QA: QA

Civilian Radioactive Waste Management System
Management & Operating Contractor

Triaxial and Shear Testing of Selected Backfill Materials

TDR-EBS-MD-000011 REV 00

August 7, 2000

Prepared for:

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DISCLAIMER

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TABLES

FIGURES

1. OBJECTIVE AND SCOPE

The Subsurface Performance Testing Section is performing tests in the Department of Energy's Atlas Facility to evaluate the performance of various backfill materials. Triaxial and shear tests were conducted on select backfill materials. The specific materials tested were: crushed tuff, overton sand, 4-10 silica sand, ¼" dolostone/marble, and limestone.

The objective of this report is to provide an estimated value for Poisson's ratio, determine internal friction angle, and stress-strain modulus of the backfill materials that were tested. These basic parameters are necessary for the selection of a backfill material to be included in the repository. This report transmits the results in both hardcopy and electronic formats plus describes the methodology and interpretation of the results. No conclusions will be drawn about the test results, as this will be the purview of other reports.

The scope of this report is to use the triaxial and shear testing information and calculate, the internal friction angle, stress-strain modulus, and provide an estimate of Poisson's ratio (Sowers 1979, p. 199) of the selected backfill materials. Standard laboratory procedures, mentioned in Section 2 of this report, were used.

2. QUALITY ASSURANCE

This report was prepared under Administrative Procedure AP-3.11Q *Technical Reports* in accordance with an approved development plan (CRWMS M&O 1999a). A Quality Administrative Procedure QAP-2-0 *Conduct of Activities* Activity Evaluation (CRWMS M&O 1999b) was completed for this report and the report was found to be quality affecting. The *Quality Assurance Requirements and Description* (DOE 2000) is applicable to this report.

The specific industry standards used to produce the raw data for the report are the American Society for Testing and Materials (ASTM) specifications D 2850-95 *Standard Test Method for Unconsolidated, Undrained Triaxial Compression Test in Cohesive Soils* (ASTM 1995) and D 3080-98 *Standard Test Method for Direct Shear Test of Soils under Consolidated Drained Conditions* (ASTM 1998). The raw data for this report comes from the interoffice correspondence entitled, *Triaxial and Direct Shear Tests Results on the Crushed Rock and Sand Samples* (Thummala 2000) and from DTN's MO0005EBSTRPBM.007 and MO0005EBSSRPBM.008 .

The ASTM method D 2850-95 for cohesive soils was also used on non-cohesion materials. The main difference between the cohesive and non-cohesive backfill materials is that they are dry and thus develop no pore water pressure. The ASTM method D 3080-98 for direct shear can be used on all soil materials (ASTM 1998, Section 5.1), thus no adjustment need be for dry, non-cohesive materials.

Microsoft Excel 97 was used to produce the graphs in Appendix A and the program was appropriate for this application. As per AP-SI.1Q *Software Management*, Sections 2.1.1 and 2.1.5, Microsoft Excel does not require software qualification as Excel is exempt from the procedure as it is used in this report.

3. DESCRIPTION OF THE TEST CONFIGURATION (PLANNED)

A description of the testing apparatus and testing procedures is included in the ASTM procedures mentioned in Section 2. The calculations to determine the internal friction angle and stress-strain modulus are based on standard geotechnical methods and are briefly described below.

The direct shear test (ASTM 1998) produces graphs of shear stress versus shear displacement with different normal stresses for each material (Thummala 2000). The highest shear stress for the different normal stresses from the laboratory recording sheets is noted (DTN: MO0005EBSSRPBM.008) and a plot of shear stress versus normal stress is developed (see Figures A-1 to A-4). A best-fit line was drawn by eye and connects the different shear stress and normal stress points for each material. The line must go through the origin of the graph since the sand and gravel tested are cohesionless materials. The internal friction angle is measured directly from this graph by a protractor. The highest shear stress is sometimes apparent from the data, but in most cases an average of the highest shear stress values is used as shown in the data for DTN: MO0005EBSSRPBM.008.

The triaxial tests (ASTM 1995) produce graphs of deviator stress versus percent strain under different confining pressures for each material (Thummala 2000) (DTN:MO0005EBSTRPBM.007). Deviator stress is defined as the normal stress minus the confining pressure. Triaxial tests can be analyzed using Mohr's circle method. In this report only the highest point on the circle will be plotted. The highest point in the circle has coordinates of p, q (where $p = (\sigma_1 + \sigma_3)/2$, $q = (\sigma_1 - \sigma_3)/2$, and σ_1 & σ_3 are the major and minor principal stresses, respectively) and are shown in Figures A-10 through A-14. A line drawn by eye, connecting the points, and going through the origin defines an angle "Ψ". The internal friction angle (ϕ) is related to this angle by (Sowers 1979, p. 201):

$$\phi = \sin^{-1}(\tan \Psi)$$

This method of calculating the internal friction angle serves as confirmation on the direct shear test method of internal friction angle determination.

The triaxial tests (ASTM 1995) also produce information related to the stress-strain modulus.

The stress-strain modulus is defined as the shear stress divided by the strain (DTN: MO0005EBSSRPBM.008). The stress and strain are usually measured at failure. For steel or concrete the point of failure is very noticeable. However, for soils, the point of failure is not so prominent and needs to be defined (Sowers 1979, pp. 199-200). The point of failure could be defined as the initial tangent modulus or failure at some level of strain (i.e. 3%, 5%, etc.). In this report, the stress-strain modulus will be given at the initial tangent and maximum shear stress (secant modulus) values (Sowers 1979, p. 189). For the initial tangent modulus a line was drawn by eye that goes through the origin and touches the tangent of the stress-strain curve. For the maximum stress modulus a line was drawn that goes through the origin and the point of maximum stress. The results for the 68.9 kPa (10 psi) (pounds per square inch) data were used to produce the stress-strain information as these results approximated the low loads expected at the top of the backfill (versus the 103.4 kPa (15 psi) or 137.9 kPa (20 psi) data).

The modulus (E) is related to the stress (σ) and strain (ε) by (Sowers 1979, p. 189):

$$E = \Delta\sigma / \Delta\varepsilon$$

Figures A-5 through A-9 show the stress strain data. The data on the figures is normalized and so the ratio of stress from the load (Sigma 1) to the confining stress (Sigma 3) must be multiplied by the confining pressure to obtain the correct change in stress:

$$E = \frac{\Delta(\text{Sigma 1/Sigma 3}) \times 10 \text{ psi}}{\Delta\varepsilon}$$

4. DESCRIPTION OF TEST CONFIGURATION (AS-BUILT)

The as-built test configuration was the same as the planned test configuration. See Section 6 of this report for a discussion of events that occurred during the test that affected test results. Information was collected directly on to laboratory recording sheets (Thummala 2000).

5. SUMMARY OF DATA FROM THE TEST

Test data is included in the correspondence (Thummala 2000) and DTN's MO0005EBSTRPBM.007 and MO0005EBSSRPBM.008 and will not be reiterated here. Included in Appendix A are graphs of the data and calculations reducing the data. Direct shear tests were not conducted on the limestone since the sample particles were too large to test in the available shear box (Thummala 2000). Dates for calibration of the equipment is included as part of the data package. A copy of the data submitted to the technical data management system is included in Appendix B. This data meets the requirements of AP-SV.1Q *Control of the Electronic Management of Data* as per Attachment I of the procedure.

As noted in the interoffice correspondence from Thummala, the material tested in the triaxial and shear equipment was large in comparison to the testing chamber. The large material may cause stress concentrations in the testing apparatus, thus providing incorrect results. However, the information provided is felt to be correct as discussed in Section 6. The results provided in the interoffice correspondence from Thummala show that the material has cohesion and this is not possible for dry sands and gravel (as the grains of material will not adhere to each other). The angle of internal friction information provided by Thummala is thus suspect as it shows cohesion in the tested material.

6. DISCUSSION OF THE TEST RESULTS

The Poisson's ratio for each material shown in Table 1 is an estimated value. The estimate is based on Sowers comments (p. 199) and is assigned a value of 0.4 for each material at failure.

Table 1 is a summary of results from Appendix A. The information in Appendix A and in Table 1 does show some variability. Due to the limited number of samples tested, lower values of the parameters were used. The limited number of samples prevents a statistical analysis of the data and thus choosing the lower value of the parameter is conservative. The low number of samples and the natural variability of the materials prevents any conclusions to be drawn about testing errors. Lower values of the parameters were also chosen to reduce the possibility that the values reported were overstated and to reduce the effect of slight irregularities in the depiction of the data.

Table 1. Material Properties

Parameter	**Material**				
	Limestone	Crushed Tuff	Overton Sand	4-10 Silica Sand	Dolostone
Poisson's Ratio (1)	0.4	0.4	0.4	0.4	0.4
Stress-Strain Modulus (3)					
Initial	12,000 psi (82.7 Mpa)	1,700 psi (11.7 Mpa)	13,000 psi (89.6 Mpa)	14,000 psi (96.5 Mpa)	12,000 psi (82.7 Mpa)
@ Maximum Stress	1,175 psi (8.1 Mpa)	500 psi (3.4 Mpa)	1,200 psi (8.2 Mpa)	780 psi (5.4 Mpa)	886 psi (6.1 Mpa)
Internal Friction Angle					
From Direct Shear	-- (2)	50.5°	36.5°	42.5°	50.5°
From Triaxial	38.7°	43.4°	36.9°	30.6°	42.4°
Use	35°	40°	35°	30°	40°

(1) Estimated values based on (Sowers 1979, p. 199). Sowers indicates that Poisson's Ratio

varies from 0.25 to 0.5 for cohesionless material.

(2) Not tested due to large size of limestone particles.

(3) Initial Stress-Strain Modulus (E_T) and the Maximum Stress-Strain Modulus (E_M) are shown in Figures A-5 to a-9.

7. REFERENCES

7.1 DOCUMENTS CITED

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1999a. *Development Plan for Data Reporting in Support of the Engineered Barrier System Testing Program*. Development Plan TDP-EBS-ND-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990802.0315.

CRWMS M&O 1999b. *Engineered Barrier Systems Performance Testing for SR and LA (12012383MT)*. Activity Evaluation, June 23, 1999. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990630.0473.

Sowers, G.F. 1979. *Introductory Soil Mechanics and Foundations: Geotechnical Engineer*ing, 4th Edition. New York, New York: MacMillian Publishing Company. TIC: 245527.

Thummala, V. 2000. "Triaxial and Direct Shear Tests Results on the Crushed Rock and Sand Samples." Interoffice correspondence from V. Thummala (Bechtel Nevada) to Dr. H.N. Kalia (CRWMS M&O), April 4, 2000, 2140-VT-00-0026, with enclosures. ACC: MOL.20000412.0784.

7.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

AP-3.11Q, Rev. 1, ICN 0. *Technical Reports*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000516.0008.

AP-SI.1Q, Rev. 2, ICN 4. *Software Management*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000223.0508.

AP-SV.1Q, Rev. 0, ICN 0. *Control of the Electronic Management of Data*. Washington, D.C.:

U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000329.1181.

ASTM (American Society for Testing and Materials) D2850. 1995. *Standard Test Method for Unconsolidated, Undrained Triaxial Compression Test on Cohesive Soils*. West Conshohocken, Pennsylvania: American Society for Testing and Materials. TIC: 241029.

ASTM D3080. 1998. *Standard Test Method for Direct Shear of Soils Under Consolidated Drained Conditions*. West Conshohocken, Pennsylvania: American Society for Testing and Materials. TIC: 247114.

DOE (U.S. Department of Energy) 2000. *Quality Assurance Requirements and Description*. DOE/RW-0333P, Rev. 10. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000427.0422.

QAP-2-0, Rev. 5. *Conduct of Activities*. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980826.0209.

7.3 SOURCE DATA

MO0005EBSTRPBM.007. Triaxial Test Results for Potential Backfill Materials. Submitted data: 05/22/2000.

MO0005EBSSRPBM.008. Shear Test Results for Potential Backfill Materials. Submitted data: 05/22/2000.

8. APPENDIX

There are two appendices to this document.

Appendix A (14 Pages):	Graphs of Data
Appendix B (1 Page):	Electronic Copy of Data

APPENDIX A

GRAPHS OF DATA

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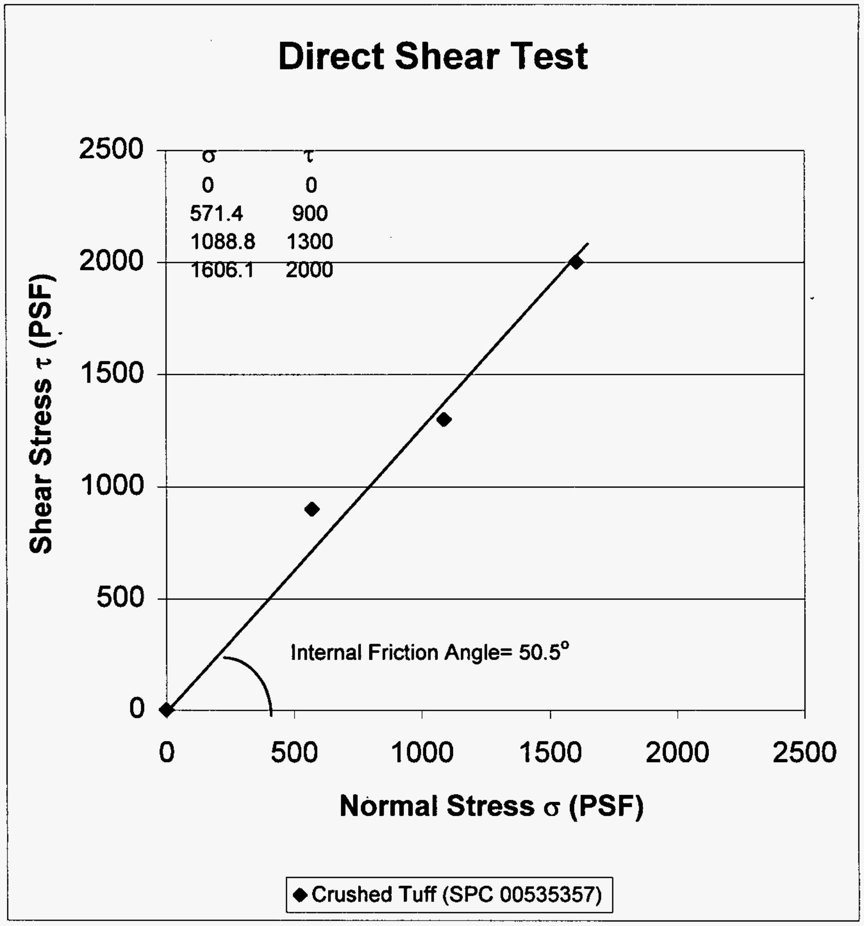

Figure A1. Direct Shear Test of Crushed Tuff using ASTM 3080-98
Note: Graph scale may be distorted by importation into document.

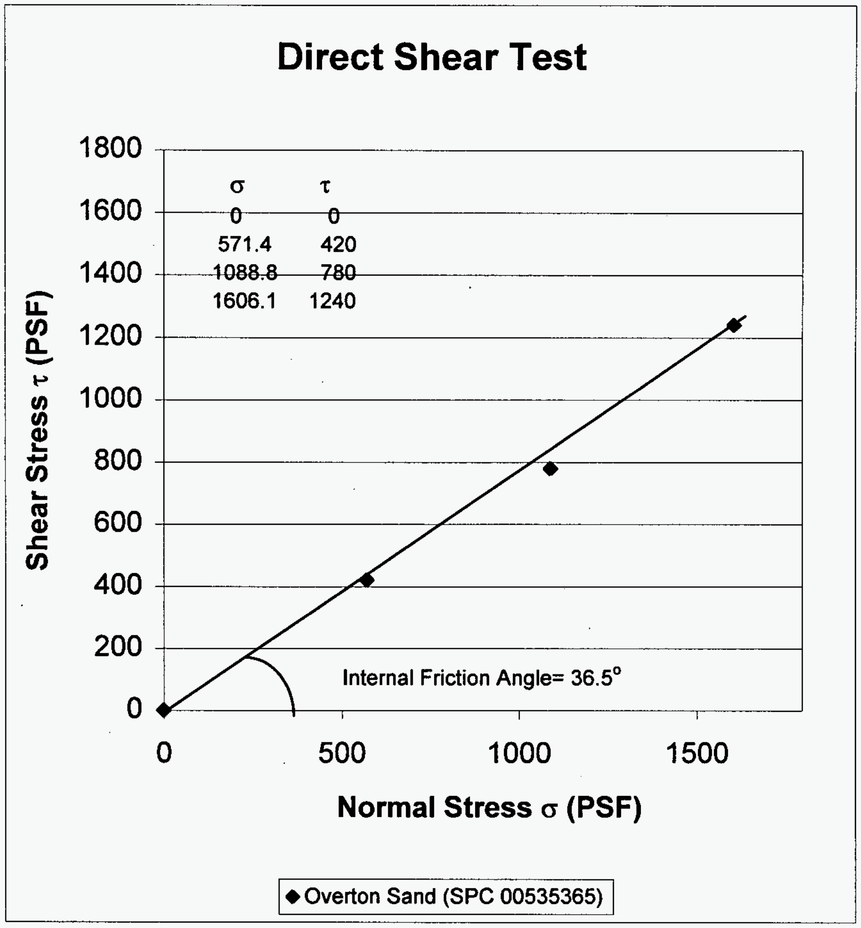

Figure A2. Direct Shear Test of Overton Sand using ASTM 3080-98
Note: Graph scale may be distorted by importation into document.

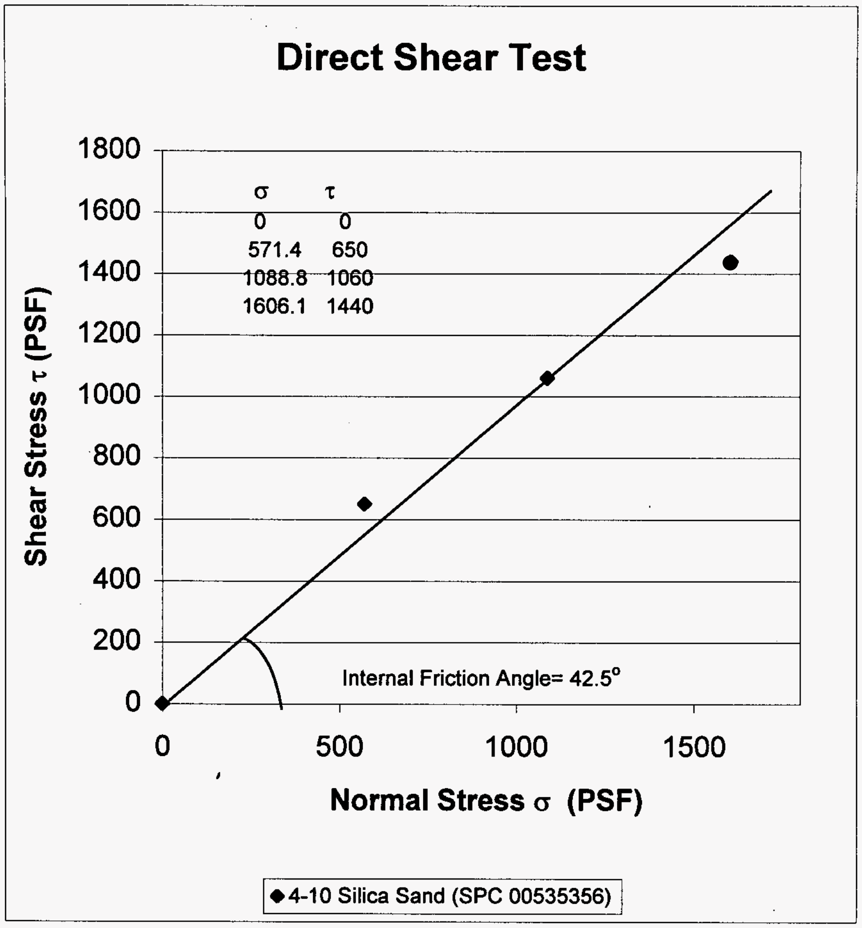

Figure A3. Direct Shear Test of 4-10 Silica Sand using ASTM 3080-98
Note: Graph scale may be distorted by importation into document.

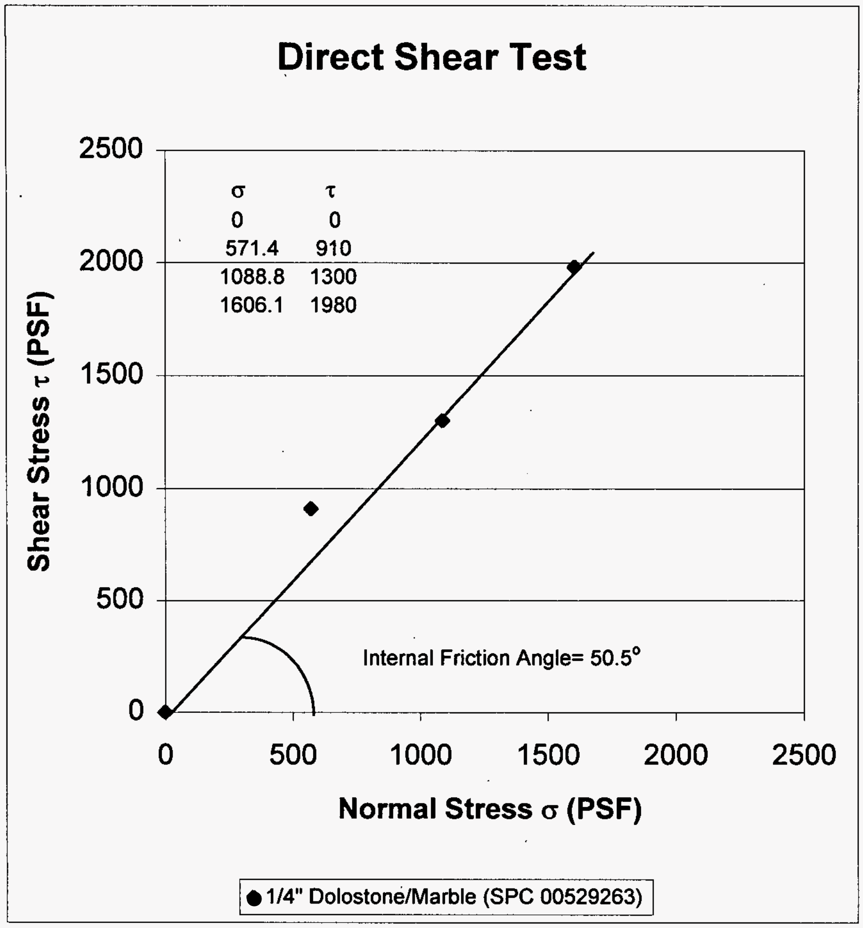

Figure A4. Direct Shear Test of ¼" Dolostone/Marble using ASTM 3080-98
Note: Graph scale may be distorted by importation into document.

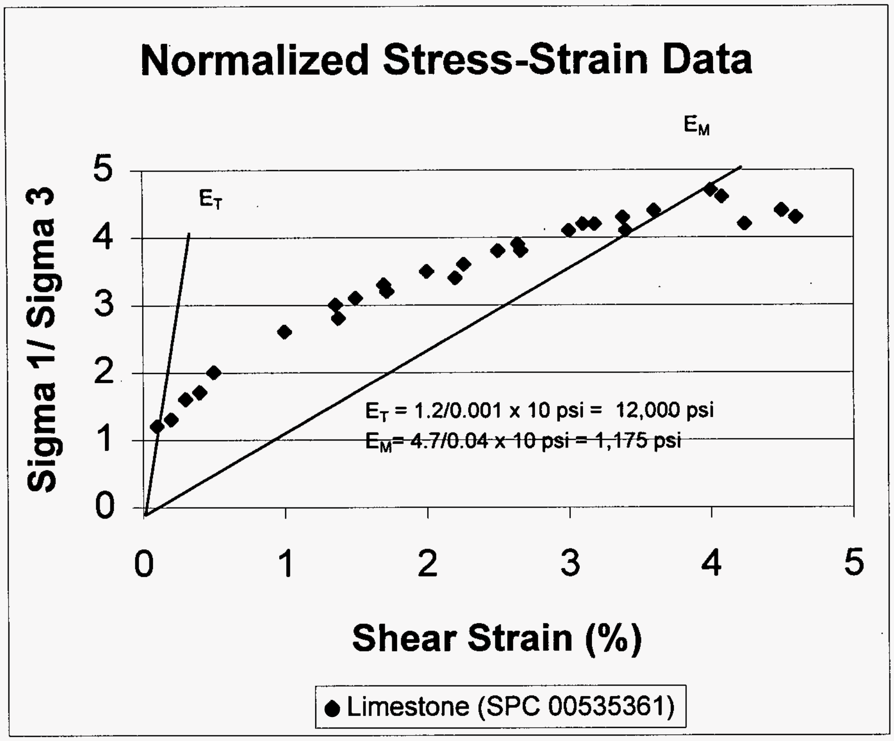

Figure A5. Normalized Stress-Strain Data for Limestone using ASTM 2850-95
Note: Graph scale may be distorted by importation into document.
Sigma 3 = 10 psi confining pressure.

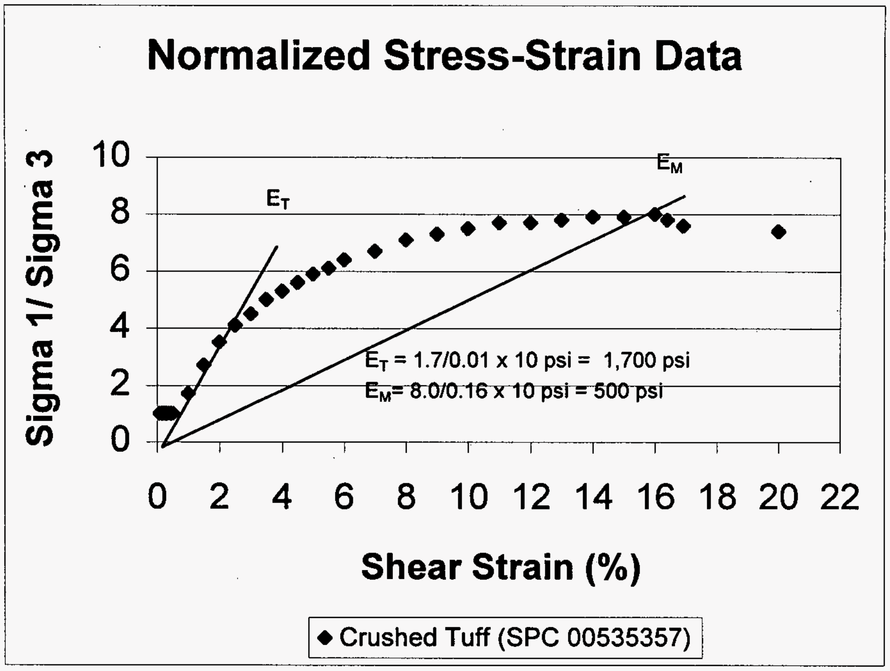

Figure A6. Normalized Stress-Strain Data for Crushed Tuff using ASTM 2850-95
Note: Graph scale may be distorted by importation into document.
Sigma 3 = 10 psi confining pressure.

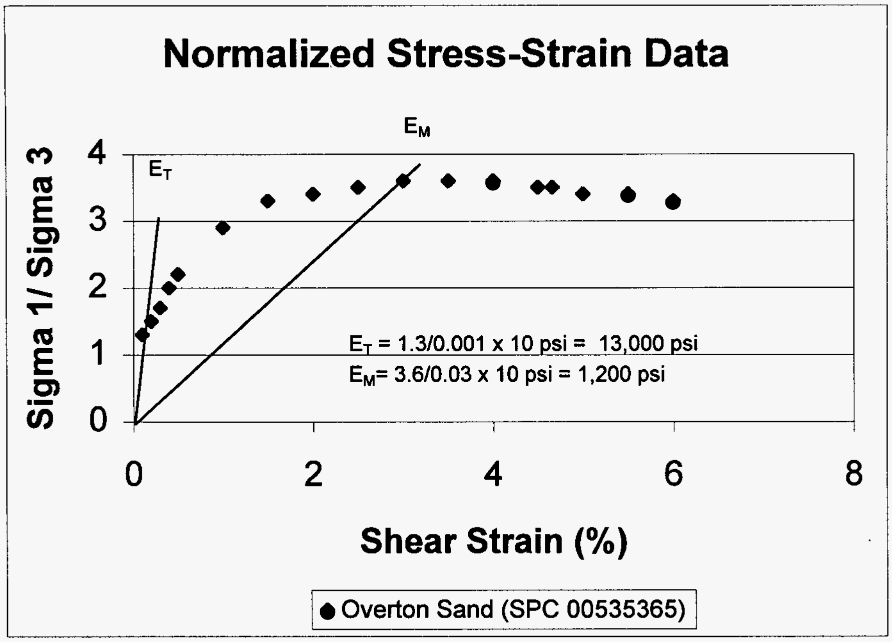

Figure A7. Normalized Stress-Strain Data for Overton Sand using ASTM 2850-95
Note: Graph scale may be distorted by importation into document.
Sigma 3 = 10 psi confining pressure.

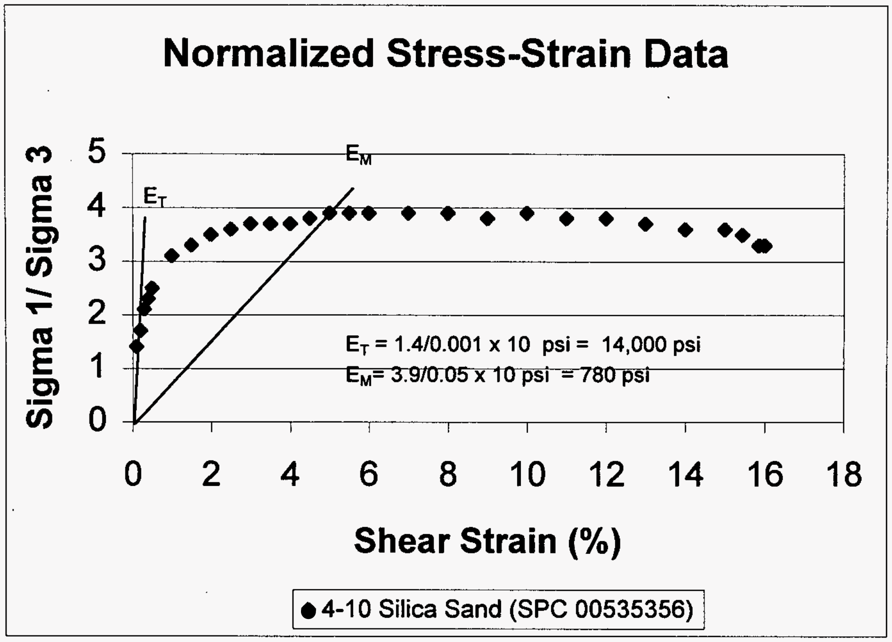

Figure A8. Normalized Stress-Strain Data for 4-10 Silica Sand using ASTM 2850-95
Note: Graph scale may be distorted by importation into document.
Sigma 3 = 10 psi confining pressure.

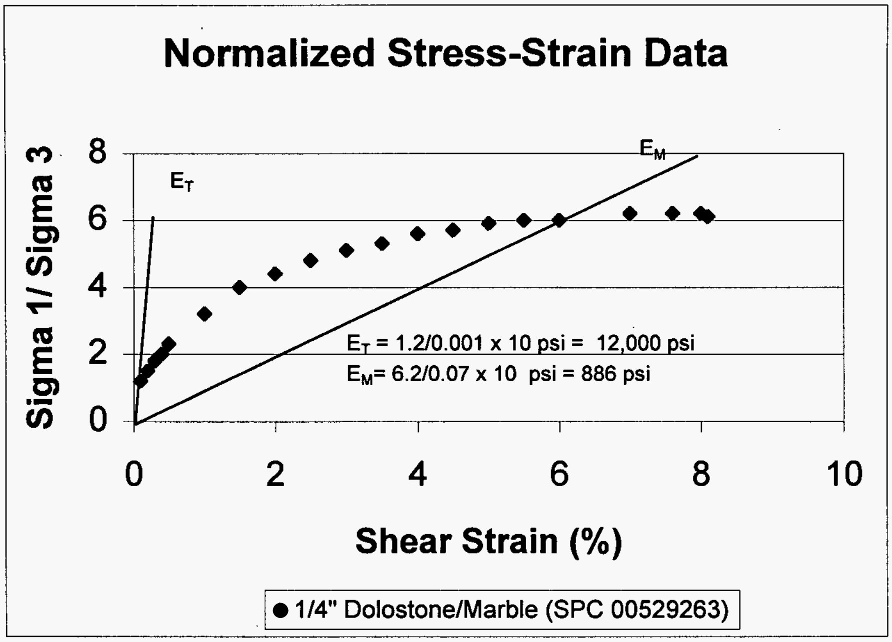

Figure A9. Normalized Stress-Strain Data for ¼" Dolostone/Marble using ASTM 2850-95
Note: Graph scale may be distorted by importation into document.
Sigma 3 = 10 psi confining pressure.

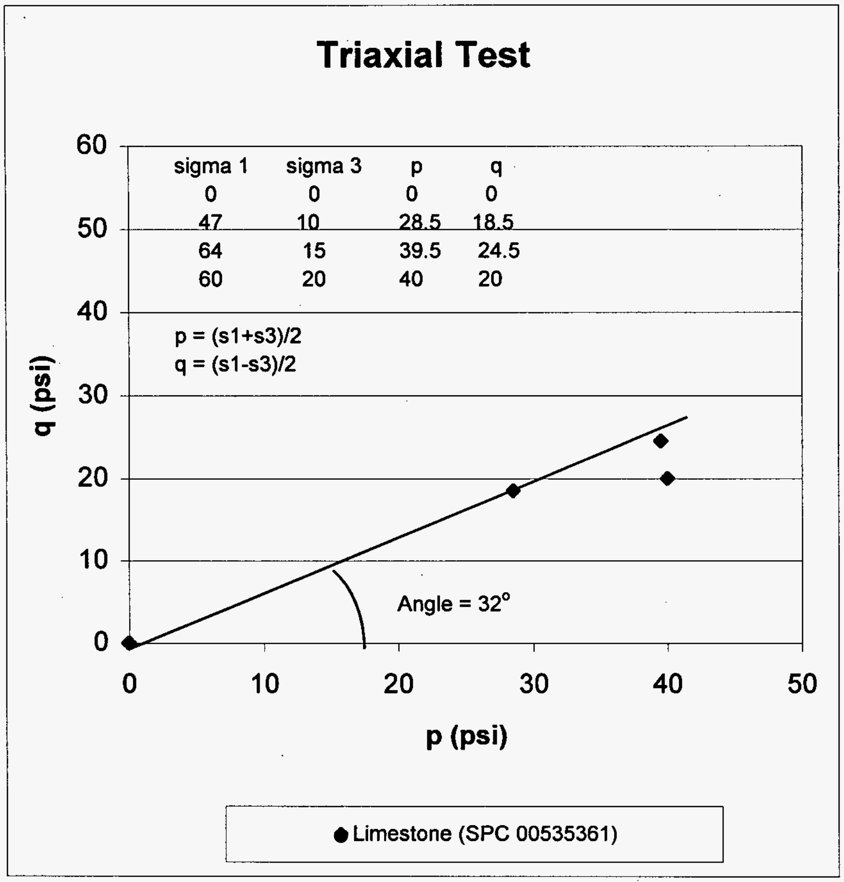

Figure A10. Triaxial Test of Limestone using ASTM 2850-95
Note: Internal Angle of Friction = Sin^{-1} (Tan 32) = 38.7°
Note: Graph scale may be distorted by importation into document.

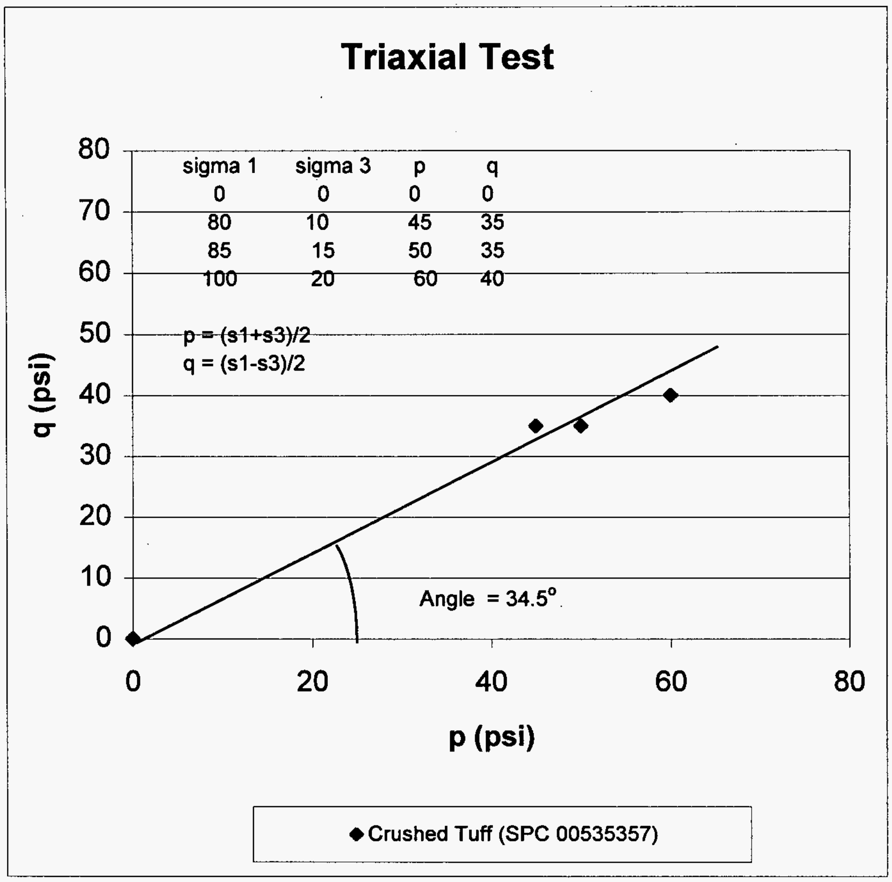

Figure A11. Triaxial Test of Crushed Tuff using ASTM 2850-95
Note: Internal Angle of Friction = $\sin^{-1}$ (Tan 34.5) = 43.4°
Note: Graph scale may be distorted by importation into document.

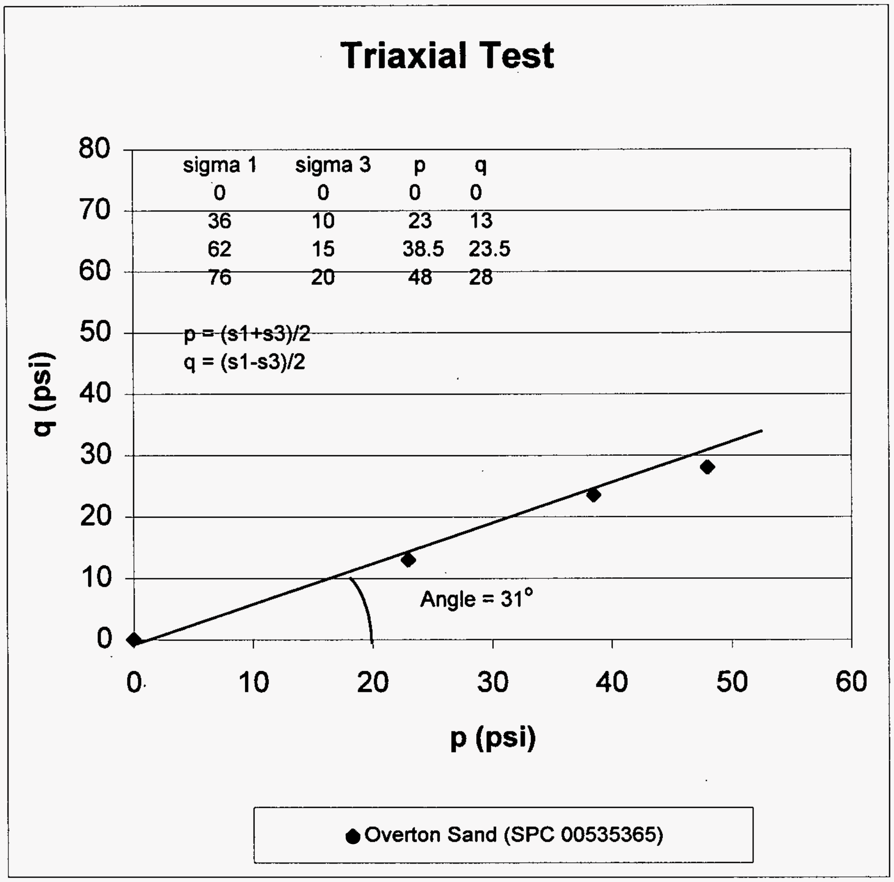

Figure A12. Triaxial Test of Overton Sand using ASTM 2850-95
Note: Internal Angle of Friction = Sin^{-1} (Tan 31) = 36.9°
Note: Graph scale may be distorted by importation into document.

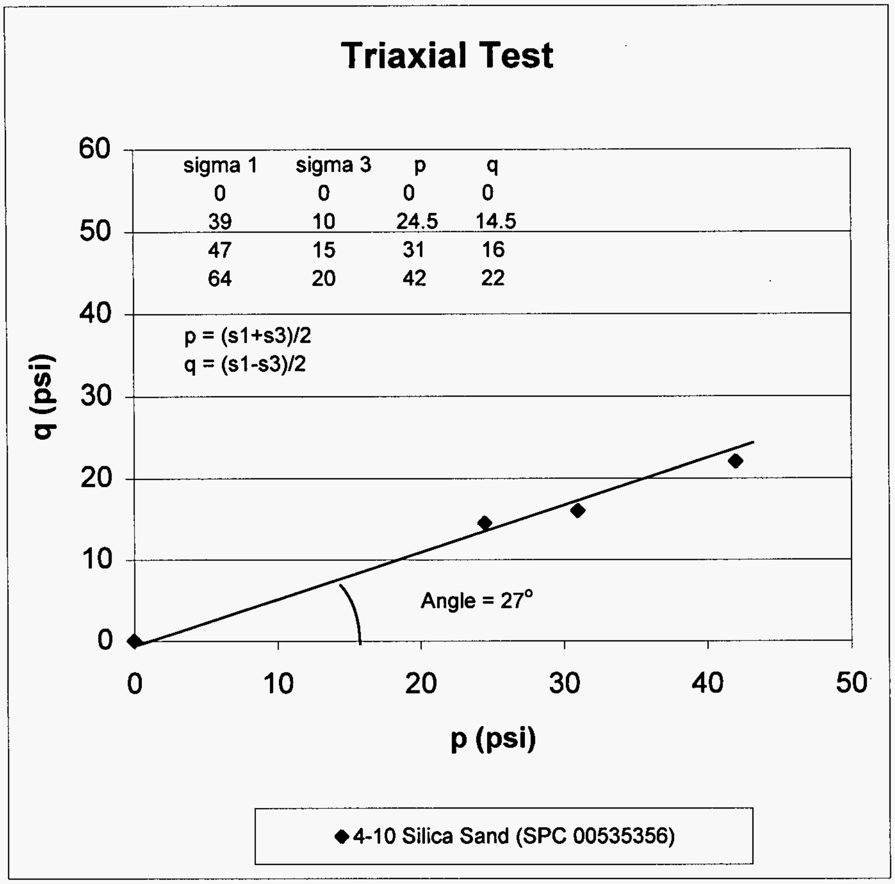

Figure A13. Triaxial Test of 4-10 Silica Sand using ASTM 2850-95
Note: Internal Angle of Friction = Sin^{-1} (Tan 27) = 30.6°
Note: Graph scale may be distorted by importation into document.

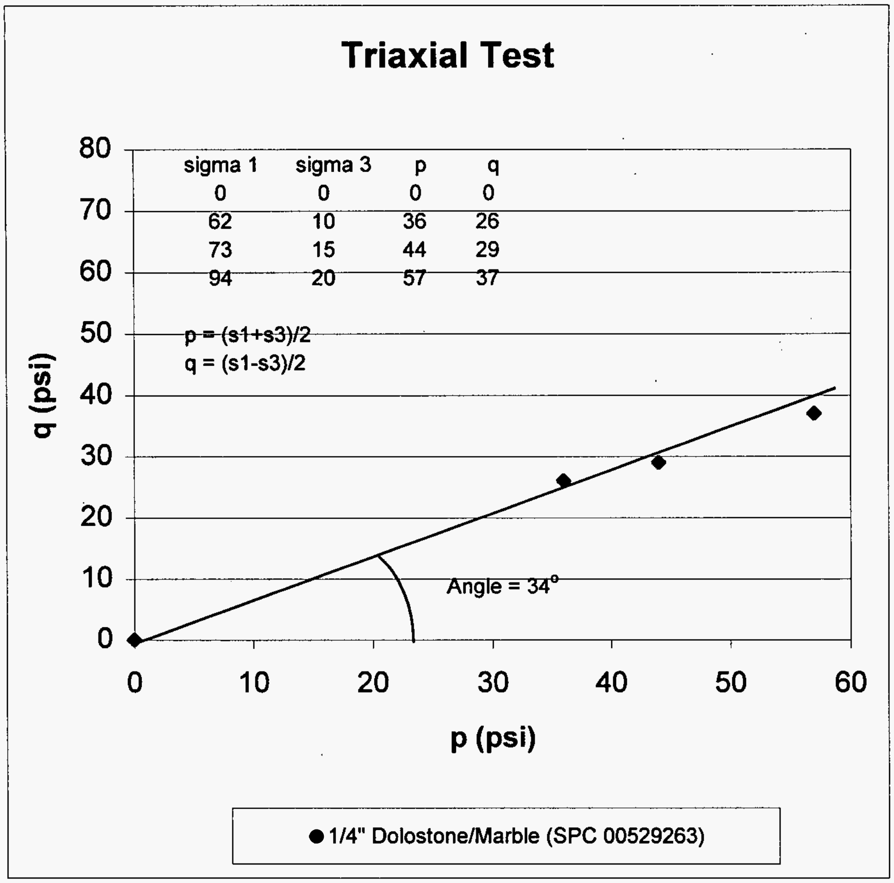

Figure A14. Triaxial Test of ¼" Dolostone/Marble using ASTM 2850-95
Note: Internal Angle of Friction = $\sin^{-1}$ (Tan 34) = 42.4°
Note: Graph scale may be distorted by importation into document.

APPENDIX B

ELECTRONIC COPY OF DATA

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Electronic copy of data attached here.

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SPECIAL INSTRUCTION SHEET

1. QA: QA

Page: 1 of: 1

Complete Only Applicable Items

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2. Record Date 08/07/2000	3. Accession Number ATTACHMENT TO: MOL.20000811.0143
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